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MARINE INDUSTRY STANDARDS
WELDING
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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Development and Evaluation of Improved Flux-Cored Welding Consumables, Phase I

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Peterson Builders
Sturgeon Bay, WI

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PROJECT NO. 7-95-4

DEVELOPMENT AND EVALUATION OF IMPROVED FLUX-CORED WELDING CONSUMABLES, PHASE I

A PROJECT OF

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

FOR

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

SHIP PRODUCTION COMMITTEE

SP-7 WELDING PANEL

2/16/98

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ABSTRACT

The objective of NSRP Project #7-95-4 is to evaluate and develop an improved flux-cored wire for use in commercial shipbuilding that can be produced within the U.S. and is comparable or exceeds those available from foreign producers. This report deals with a portion of the first phase consisting of evaluating FCAW wires from U.S. and foreign manufacturers to identify the differences in weldability, arc characteristics and quality .

The electrode evaluation consisted of a semiautomatic/mechanized portion and an automatic (robotic) portion. The semiautomatic/mechanized portion consisted of welding both fillet and butt joints, evaluating feedability, operability, slag removability and smoke/fume generation. The automatic (robotic) portion consisted of welding fillet joints and evaluating operability, seam tracking, parameter variation, depth of weld root penetration, travel speed and multipass fillet welding over slag.

Overall there was no significant performance advantage of foreign wires over the domestic wires tested. However, there were differences attributed to the various shielding gases. For semiautomatic/mechanized welding, 75% Ar - 25% CO_2 wire had the best operability, mainly in out-of-position welding. For automatic welding, 100% CO_2 wires provided the best travel speed and penetration with comparable operability. All wires deposited sound multipass fillet welds over slag.

CONTENTS

INTRODUCTION:

The objective of NSRP Project #7-95-4 is to evaluate and develop an improved flux-cored wire, for use in commercial shipbuilding, that can be produced within the U.S. and is comparable to or exceeds those available from foreign producers. In order to insure the project objective is obtained, the project's technical approach was divided into three phases. The first phase consists of procuring and evaluating FCAW wires from U.S. and foreign manufacturers to identify the differences in weldability, arc characteristics and quality . Phase two involves developing and testing a prototype FCAW wire. The third phase includes developing and producing a commercially available FCAW wire, then providing other NSRP SP-7 panel member shipyards the opportunity to evaluate the developed wire. If the welding evaluation of Phase I reveals minimal differences between the foreign and domestic wires, then the project would be canceled.

This report covers the results from Phase I welding test comparison of weldability, arc characteristics, and quality between the foreign and domestic wires picked for this evaluation.

OVERVIEW:

Six wires (3 non-domestic and 3 domestic supplied) were procured for this evaluation. These six wires were picked through a survey sent to the following three foreign yards and five domestic shipyards asking them to identify their most used FCAW wire for carbon steel welding.

Foreign Yards Surveyed

Hitachi Zosen
Odense Steel Shipyard
Samsung Heavy Industries

Domestic Yards Surveyed

Avondale
Bath Iron Works
Ingalls
NASSCO
Newport News

The six wires picked for the evaluation are:

Non-Domestic Wires

1.2 mm Nittetsu SF-1, used with 100% CO_2 shielding gas
1.2 mm Kobe DW-100, used with 100% CO_2 shielding gas
1.2 mm Kobe DW-55L, used with 100% CO_2 shielding gas

Domestic Wires

0.045” ESAB DS II 71, 100% CO_2 shielding gas
0.052” ESAB DS II 71, 100% CO_2 shielding gas
0.045” ESAB DS II 70 Ultra, 75% Ar - 25% CO_2 shielding gas

Table 1 shows all-weld-metal chemistries of each electrode taken from multipass fillet welds on ABS Grade A plate.

Table 1
Electrodes All Weld Metal Chemistries

Filler Metal Chemistry	Nittetsu SF-1	Kobe DW-100	Kobe DW-55L	.045” ESAB DS II-71	.052” ESAB DS II-71	.045” ESAB DS II-70 Ultra
C	0.07	0.07	0.06	0.05	0.03	0.06
Mn	1.30	1.20	1.17	1.17	1.09	1.16
Si	0.50	0.44	0.36	0.40	0.38	0.34
P	0.013	0.015	0.011	0.010	0.015	0.015
S	0.015	0.014	0.013	0.014	0.011	0.011
Ni	0.03	0.02	0.86	0.02	0.02	0.02
Mo	0.01	<0.01	<0.01	0.03	<0.01	<0.01
Cr	0.06	0.02	0.02	0.02	0.02	0.02
V	0.01	0.01	0.01	0.02	0.02	0.02
Ti	0.06	0.05	0.05	0.05	0.05	0.04
Cb	0.01	0.01	0.01	0.01	0.01	0.02
Cu	0.15	0.02	0.02	0.02	0.02	0.02

Each wire was evaluated for its arc starting characteristics, arc stability, amount of spatter, bead shape and appearance. Each characteristic was rated on a scale of 1 to 5, with 1 being poor, 3 being fair and 5 being great. This rating system was wholly subjective based on the observations of the welding technician and engineer. To assure accurate results the following precautions were taken:

- The two technicians that did the testing had extensive experience both as production welders and welding engineering technicians.

- The same technician welded with all the wires for a given test condition to provide a consistent comparison between the wires.
- The graphs depicting the results also show +/- 1 standard deviation.

Other comparison tests included wire feedability, slag removability, and fume generation.

Fillet welds were visual (VT) inspected, macroetched and break tested. The butt joints were magnetic particle (MT), radiographic (RT) and visual (VT) inspected. All visual, magnetic particle, and radiographic inspections were done in accordance with the specifications listed in Table 2.

Table 2
NDT Inspection Standards

Inspection Method	Inspection Criteria	Acceptance Criteria
VT	MIL-STD-271F	NAVSHIPS 0900-003-8000 Cl.-1
MT	MIL-STD-271D	NAVSHIPS 0900-003-8000 Cl.-1
RT	MIL-STD-271D	NAVSHIPS 0900-003-9000 Cl.-1

The welding comparison test originally consisted of semiautomatic and mechanized welding of fillet and butt welds. The Results of that testing showed the domestic wires performed equal to or better than the foreign wires. Due to the extensive use of these particular foreign wires in automatic applications, it was decided to modify the project to include comparing the domestic and foreign wires in automatic (robotic) applications. This was a no cost increase/extension to the contract approved by the SP-7 panel. Fillet welds were welded in the horizontal (2F) and vertical (3F) positions comparing each wire's seam tracking, parameter variation, arc stability, bead shape, puddle control, and spatter characteristics using the same 1 to 5 rating scale as the semiautomatic/mechanized evaluation. Also compared was the VT quality of final weld and root penetration from macro.

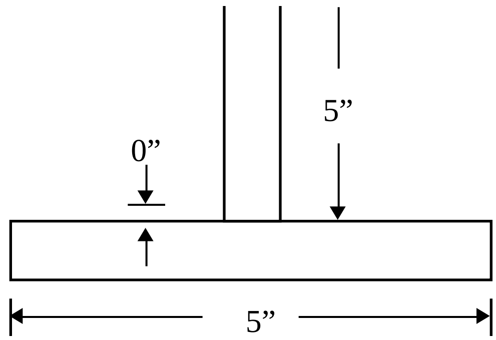
An additional attribute evaluated was the ability for an electrode to multi-pass fillet weld over slag.

Part 1: <u>SEMIAUTOMATIC AND MECHANIZED EVALUATION</u>

A. ***Fillet Welding:***

Method:

Seventy two fillet weld assemblies were fit-up using 3/8" thick ABS Grade A plate. All test assemblies were 18" long. The joint design is shown below.


5”
0”
5”

All joints were sanded to bare metal. Each wire was used to weld two joints in each the 2F, 3F, and overhead (4F) positions using semi-automatic FCAW. This number of joints and positions was then repeated using mechanized FCAW. The target fillet weld size for both applications was _" (6 - 7 mm).

The welding technician evaluated each wire for its starting characteristics, arc stability, amount of spatter, bead shape and appearance. A weld macro was taken from one end of each joint to evaluate weld penetration into the base metal at the root. Each joint was also break tested by carbon arc gouging the first side, then notching and breaking the second weld bead. The break area was then evaluated by counting the number and size (0.021" and larger diameter) of porosity on the fracture surface.

Results:

Figures 1 through 3 show each average rating of arc starting, arc stability, weld spatter, bead shape and appearance for each position. The chart bars are the combined average rating of each characteristic and the lines show a range of ± 1 standard deviation of each characteristic. The standard deviation is shown to give a more accurate picture of the results.

Figure 1
Operability Results (Fillets) 2F

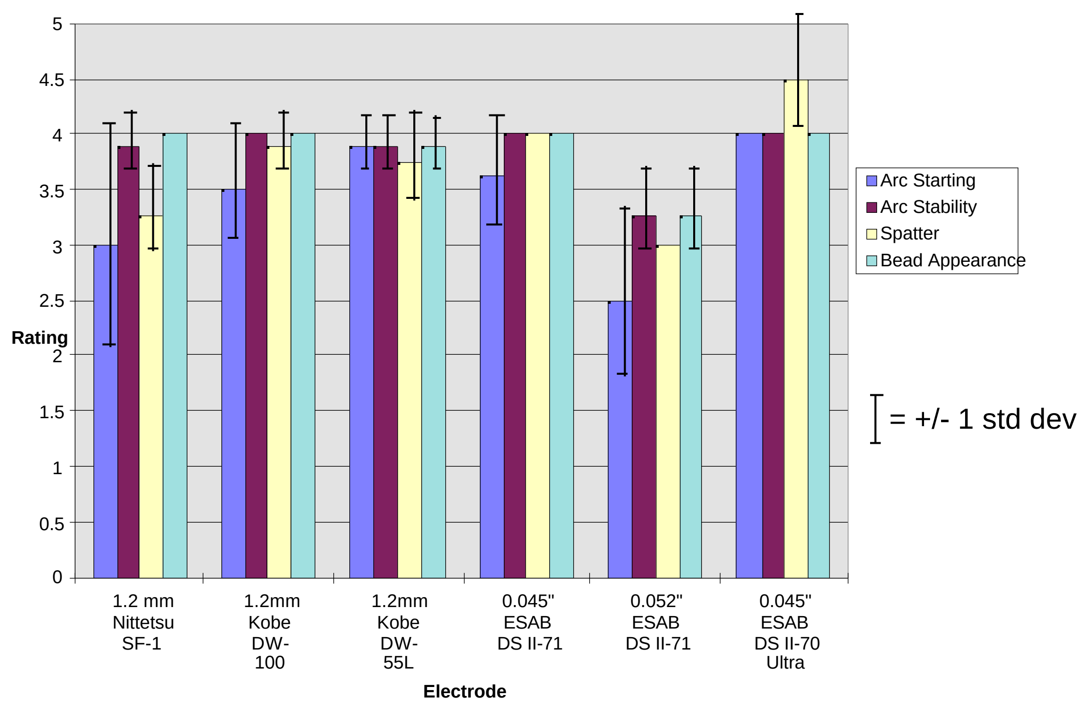


Figure 2

Operability Results (Fillets) 3F

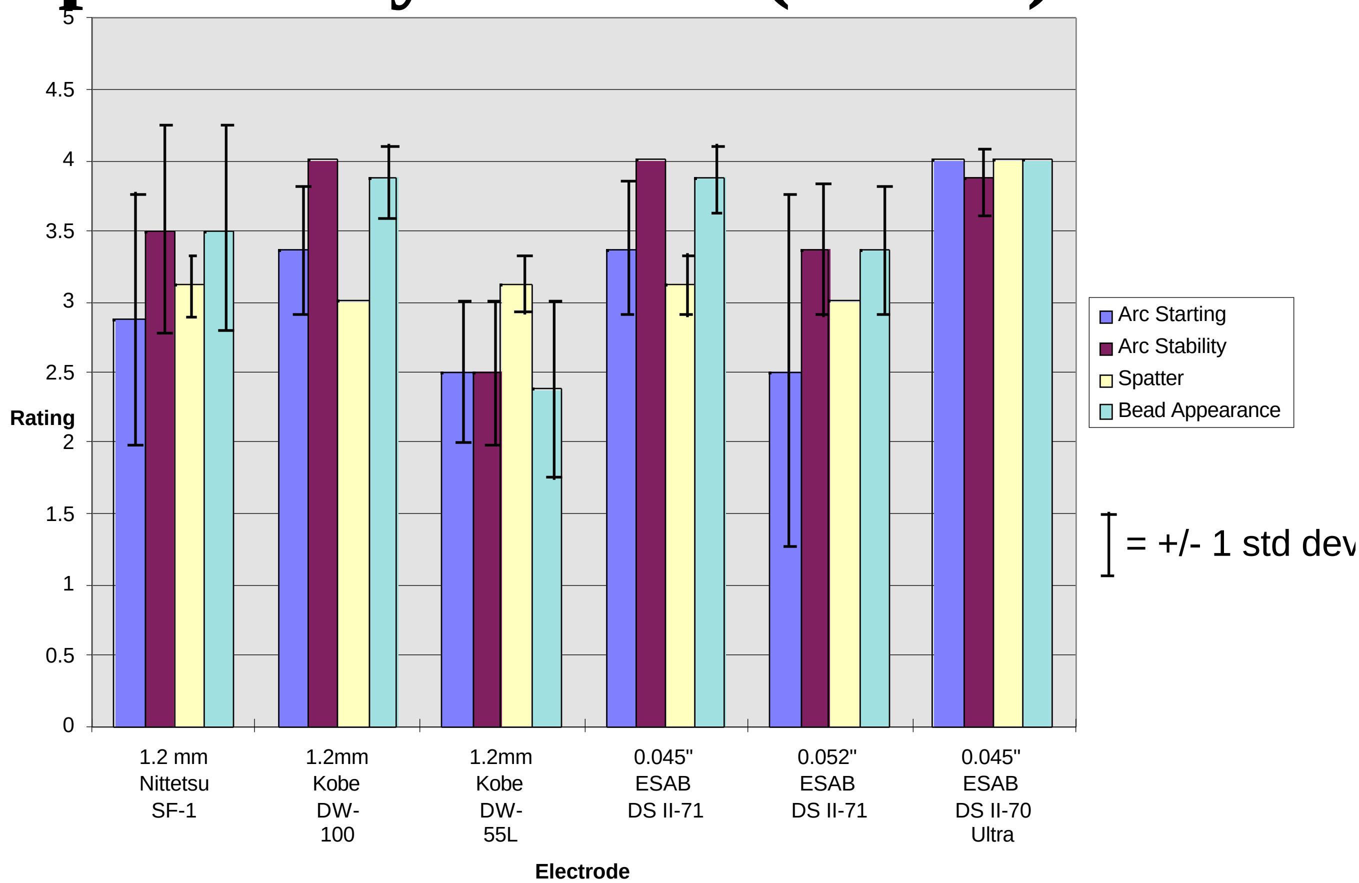
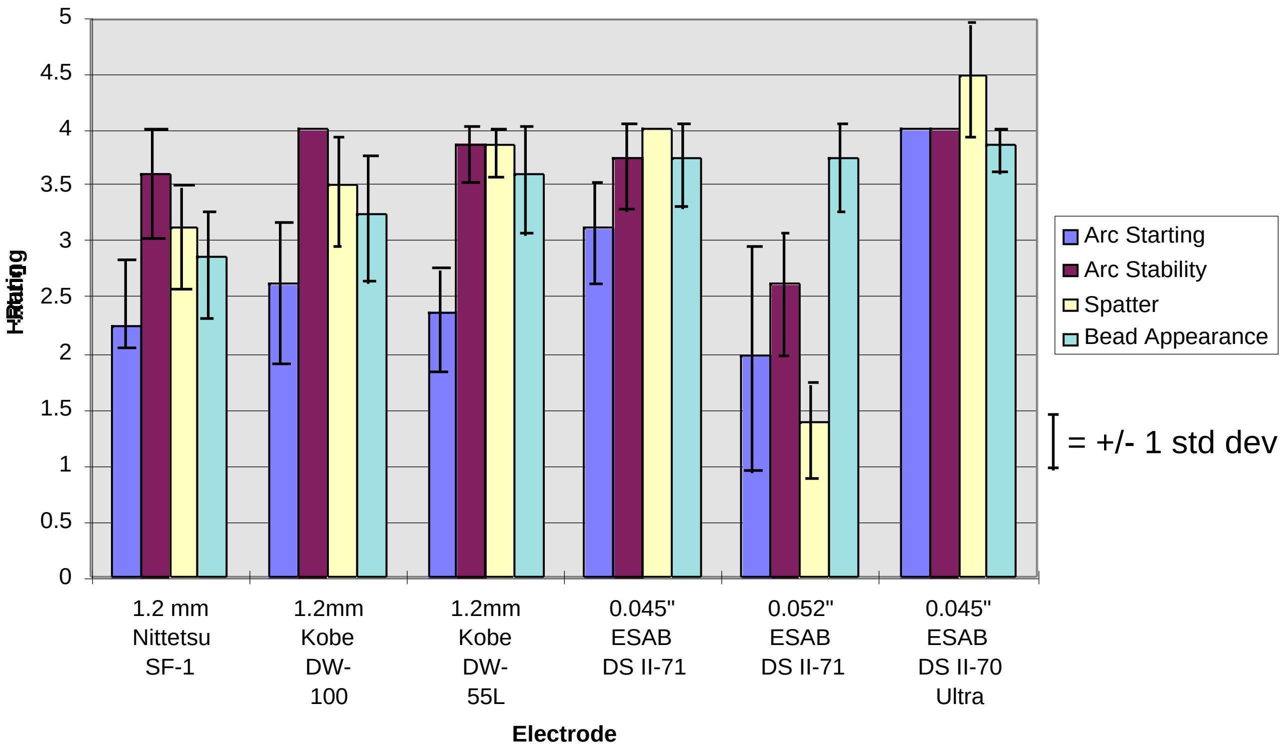


Figure 3
Operability Results (Fillets) 4F



There was no significant difference in the operability characteristics between electrodes in the 2F position. For out of position welding (3F and 4F), ESAB's DS II-70 Ultra using 75% Ar - 25% CO_2 shielding gas had better performance than the other electrodes which utilized 100% CO_2 shielding gas. The 75% Ar - 25% CO_2 shielding gas provides a more stable arc with better puddle control.

Table 3 shows the porosity percentage from the fillet weld break test. Those percentages were calculated as follows

% Porosity = [(# of pores * pore diameter)/weld length]*100

Table 3

Fillet Weld Break Test Results

Porosity Percentage

Position	Semiautomatic					
	2F		3F		4F	
	Diameters	Diameters	Diameters	Diameters	Diameters	Diameters
Electrode	>/=0.021	> 1/16"	>/=0.021	> 1/16"	>/=0.021	> 1/16"
1.2 mm SF-1	3.8	0.2	3.3	0.0	2.4	0.0
1.2 mm DW-100	6.8	0.4	2.4	0.0	2.5	0.0
1.2 mm DW-55L	7.2	3.3	1.1	0.0	6.0	2.2
.045" DSII-71	16.1	4.0	3.1	0.0	2.8	0.0
.052" DSII-71	5.6	0.6	4.0	1.0	9.2	0.6
.045" DSII-70 Ultra	15.5	12.6	2.6	0.6	3.0	0.2

Position	Mechanized					
	2F		3F		4F	
	Diameters	Diameters	Diameters	Diameters	Diameters	Diameters
Electrode	>/=0.021	> 1/16"	>/=0.021	> 1/16"	>/=0.021	> 1/16"
1.2 mm SF-1	1.7	0.4	2.4	0.0	0.0	0.0
1.2 mm DW-100	2.7	0.2	7.2	1.0	0.2	0.0
1.2 mm DW-55L	7.5	0.6	4.0	0.0	0.5	0.0
.045" DSII-71	5.3	1.0	5.9	0.6	0.3	0.0
.052" DSII-71	3.5	0.0	1.2	0.0	0.0	0.0
.045" DSII-70 Ultra	16.1	4.2	6.4	0.0	0.0	0.0

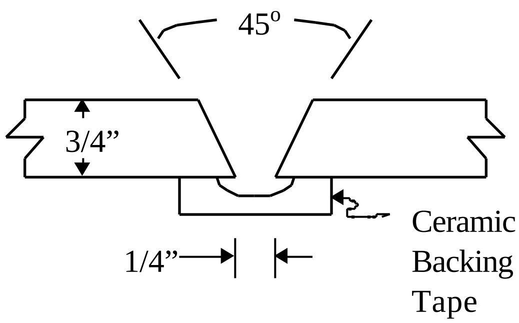
The .045” diameter ESAB DS II 70 Ultra showed an unusually high porosity percentage even though it operated good with no evidence to suggest porosity during welding. The high values are attributed to a heat of wire obtained that had diffusible hydrogen levels above that allowed in the electrode specification.

Macro results showed that penetration at the root was acceptable for all wires. ESAB .045” DSII-70 Ultra with 75% Ar - 25% CO_2 shielding gas showed the least amount of penetration, although it was acceptable.

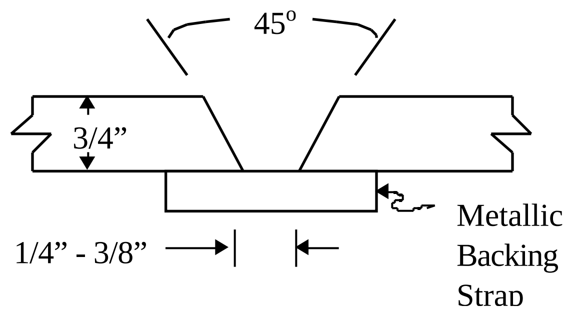
B. ***Butt Welding:***

<u>Method:</u>

Twelve butt joint assemblies were fit-up using 3/4” thick ABS Grade B plate. Each weld assembly was 36” long. Each wire was used to weld two joints. One of the joints was welded in the 3G position. The other joint was welded in the 4G position. The specific joint designs are as follows.



Joint Design for 3G Butt Welds



Joint Design for 4G Butt Welds

All welding was semiautomatic using an Oxomatic FW-2-400-10 gas cooled torch. The welding technician again evaluated each wire for its starting characteristics, arc stability, amount of spatter, bead shape and appearance, and weld puddle control. Again he gave each characteristic a rating number from 1 to 5, with 1 being worst condition and 5 being the best.

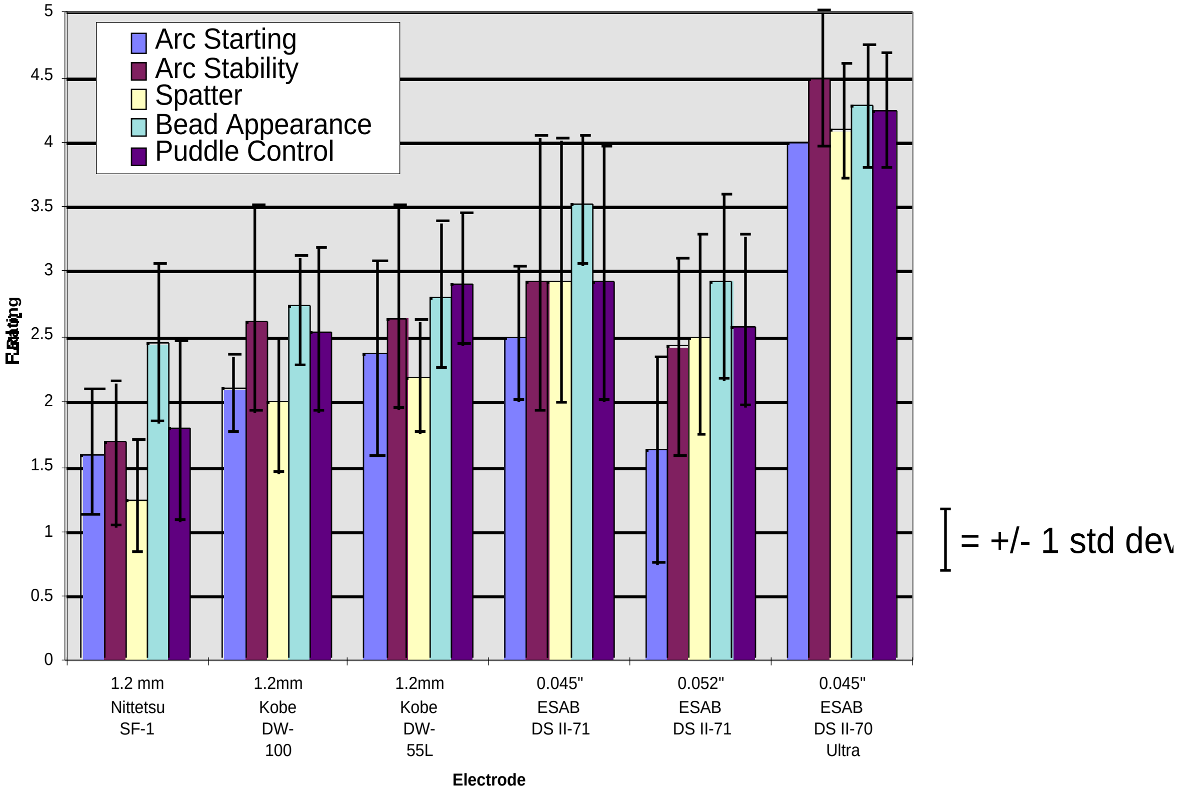
The completed joints were VT, MT and RT inspected.

<u>Results:</u>

Figure 4 shows the average rating of arc starting, arc stability, weld spatter, bead shape and appearance. The chart bars are the combined average rating for each characteristic and the lines show a range of $\pm$ 1 standard deviation of each characteristic.

Figure 4

Operability Results (3G & 4G Butts)



ESAB's DS II-70 Ultra using 75% Ar - 25% CO_2 shielding gas was the preferred electrode for this out of position welding. The other electrodes using CO_2 shielding gas had comparable operability characteristics.

All joints passed VT and MT once the joints were ground. Table 4 shows the RT results for each joint as well as the RT results for the joints welded in the feedability comparison tests described in the following subsection.

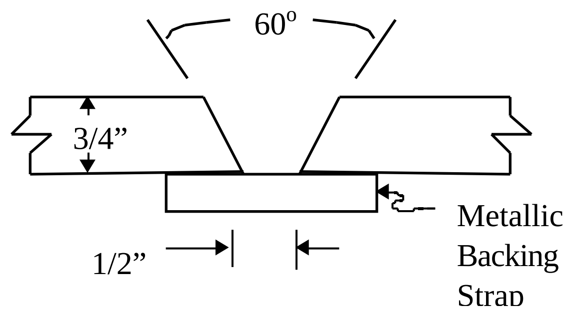
Table 4
RT Results

	Semi-Auto Weldability Test		Mech. Feedability Test
Position	3G	4G	3G
1.2 mm Nittetsu SF-1	Slag	Porosity & Slag	Sat.
1.2mm Kobe DW-100	Sat.	Porosity	Sat.
1.2mm Kobe DW-55L	Sat.	Sat.	Sat.
0.045" ESAB DS II-71	Sat.	Sat.	Sat.
0.052" ESAB DS II-71	Slag	Porosity & Slag	Sat.
0.045" ESAB DS II-70 Ultra	Sat.	Sat.	Sat.

C. ***Feedability*****:**

Method:

Six butt joint assemblies were fit-up using 3/4” thick ABS Grade B plate. The assemblies were 24” long. Each wire was used to weld one joint in the 3G position. The specific joint design is shown below.



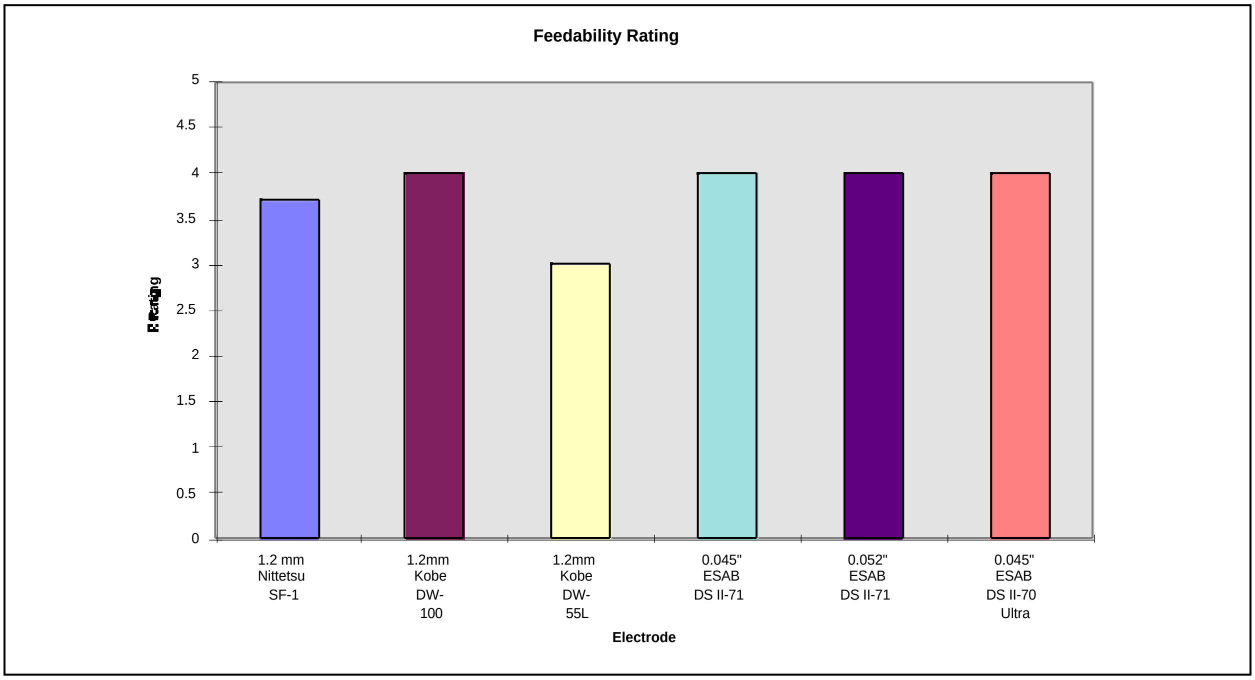
Joint Design for Feedability Test Welds

New feed rollers, conduit, and contact tip were used on the wire feeder and torch for every joint. Feed roll pressure was kept constant for all the wires and no wire straighteners were used. Half of the welding of each test plate was done with the conduit cable in a “natural” bend condition and half with the conduit cable having a “loop” of approximately 18” in diameter. The semiautomatic torch was clamped to a tractor and oscillator to keep torch motion as consistent as possible between wires.

Results:

RT results are shown in Table 4 above. All wires welded with no feedability problems. All feeding components showed normal wear. Results indicate no major differences in feedability between electrodes. Figure 5 shows the specific feedability rating for each of the wires.

Figure 5
Feedability Results

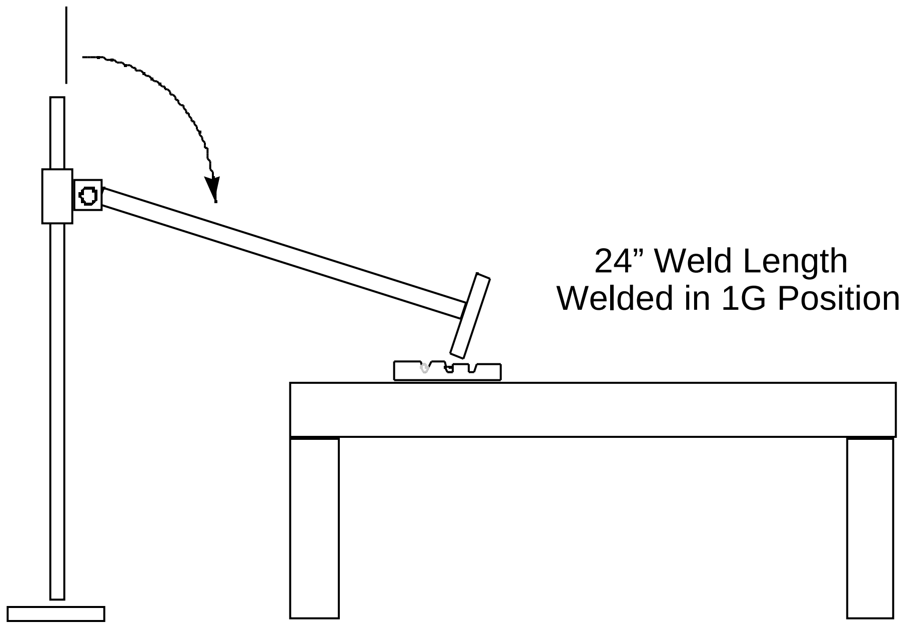


D. ***Slag Removability Test:***

<u>Method:</u>

Three grooves were carbon arc gouged in six 3/4" thick ABS Grade B plates. Each groove was about 1/2" deep and 26" long with the side walls beveled at approximately 45^{o} included angle. Each wire was used to weld 1 pass in each of three grooves in one plate. After each pass, the plate was struck with a 30 lb weight attached to a 40" long pipe. The other end of the pipe was attached to a stand allowing the weight to swing in an arc. Figure 6 shows the testing apparatus used. Two minutes was allowed to pass from the termination of the arc to the time of impact on each pass. Impact was done by placing the weighted arm in the vertical position and allowing it to swing down to approximately 25^{o} below horizontal, impacting as close to the weld as possible. The length of slag removed was recorded for each bead.

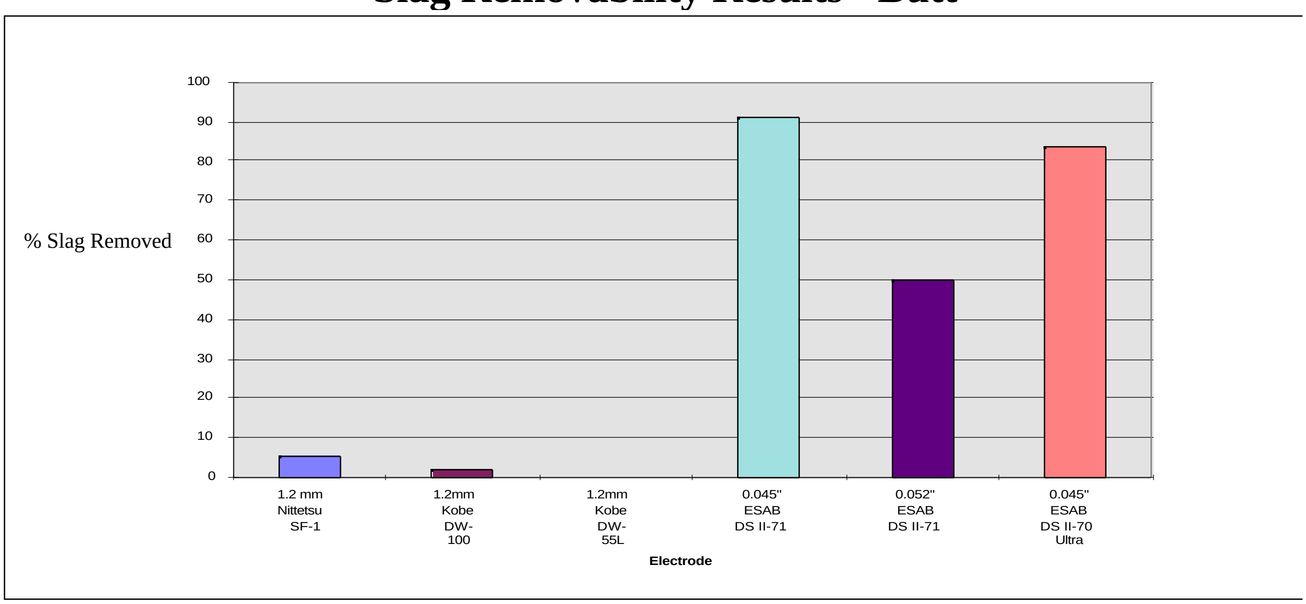
Figure 6
Test Method - Slag Removability



Results:

The slag removability results are shown in Figure 7. The domestic wires performed much better than the foreign wires.

Figure 7
Slag Removability Results - Butt



No slag removability tests were performed on fillet assemblies. During fillet assembly welding, however, the slag was easily removed for all wires.

E. *Smoke/Fume Generation Comparison:*

Method:

Smoke/fume generation comparison was completed by mechanized welding a bead on plate in the 3G position. While welding, the lab technician and welding engineer visually evaluated the amount of smoke/fumes being generated. The six wires were compared and ranked.

Results:

Figure 8 shows the ranking from the fume generation evaluation listing the wire having the least visual smoke to the wire having the most visual smoke. The wires grouped together had the same smoke/fume generation.

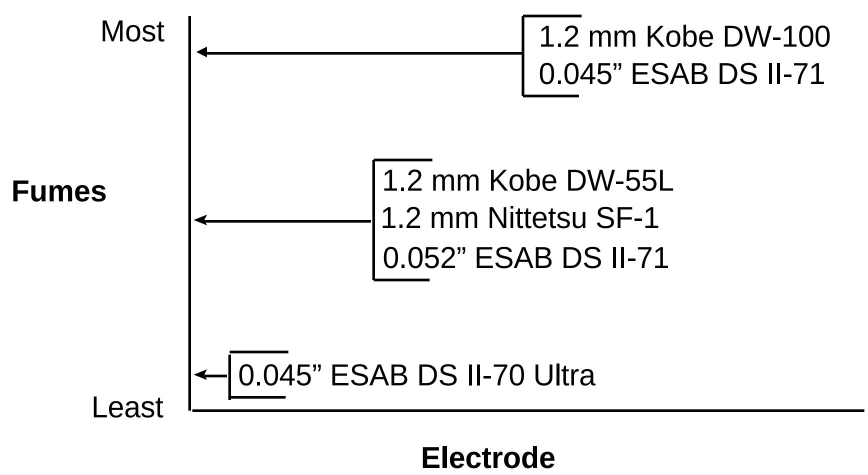
ESAB DS II-70 Ultra was slightly better than the other wires. This is attributed to the use of 75% Ar - 25% CO_2 shielding gas. There was small overall difference between the wires. Although the data outlined in Figure 8 is judgmental based on visual observation, it is consistent with quantitative data reported in the December 1995 Issue of the AWS Welding Journal. [1]

[1] Ferree, Stanley E., "New Generation of Cored Wires Creates Less Fume and Spatter", AWS Welding Journal, December 1995, p48.

Figure 8

Fume Generation Results

Small Overall Difference



F. *Conclusions:*

The following can be concluded from semiautomatic and mechanized evaluation:

- All wires were capable of producing sound welds as demonstrated by VT, MT, macros, fillet break tests, and RT of butt welds.
- The operability of ESAB's DS II-70 Ultra wire which used 75% Ar - 25% CO_2 was preferred over the wires using 100% CO_2. This preference was especially prevalent for out of position welding.
- The slag removability during fillet welding was comparable for all wires. There were no great differences noted between wires.
- For butt welding, the ESAB wires' slag was easily removed while the Kobe and Nittetsu wires produced tightly adhering slag.
- There were small overall differences in the amount of smoke/fumes generated between wires. ESAB's DS II-70 Ultra had the least amount of smoke/fumes which was attributed to the 75% Ar - 25% CO_2 shielding gas.

Part II: AUTOMATIC (*ROBOTIC*) EVALUATION

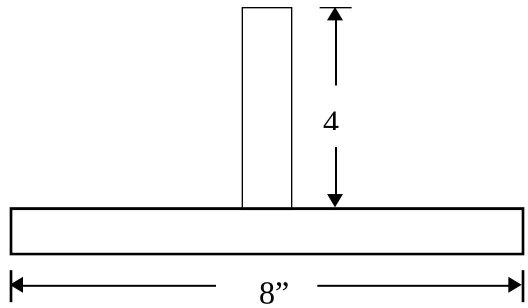
A. *Fillet Welding*:

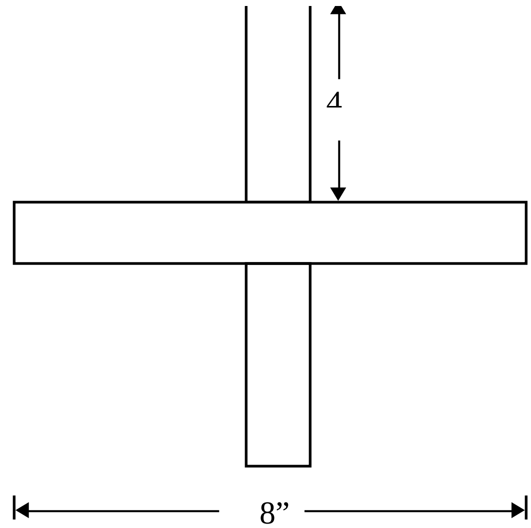
Method:

For the horizontal position, thirty-six fillet weld test assemblies were fit-up using 3/8" thick ABS Grade A plate. All test assemblies were 36" long. All joints were sanded to bare metal. Each wire was used to weld 6 test assemblies. Once optimum parameters were established with each wire, all six test assemblies were welded at those parameters. The torch/work angles were held constant as welding progressed from one end of the joint to the other without stopping.

For the vertical position, eighteen fillet weld assemblies were fit-up using 1/2" thick ABS Grade A plate. All test assemblies were 18" long. All joints were sanded to bare metal. Each wire was used to weld 3 test assemblies for a total of 12 welds. All three test assemblies were welded at the optimum parameters established for each wire. The torch/work angles were held constant as welding progressed from one end of the joint to the other without stopping.

The joint designs for each position are shown below.





Joint Design for Horizontal

Joint Design for Vertical

The welding technician and engineer evaluated each wire for its starting characteristics, arc stability, amount of spatter, seam tracking, parameter variations, bead shape and appearance and puddle control using the 1 to 5 rating system.

Results:

Figures 9 and 10 shows each average operability characteristic rating for each position welded. There was not a great difference in operability between wires in each position.

Figure 9
Results (2F)

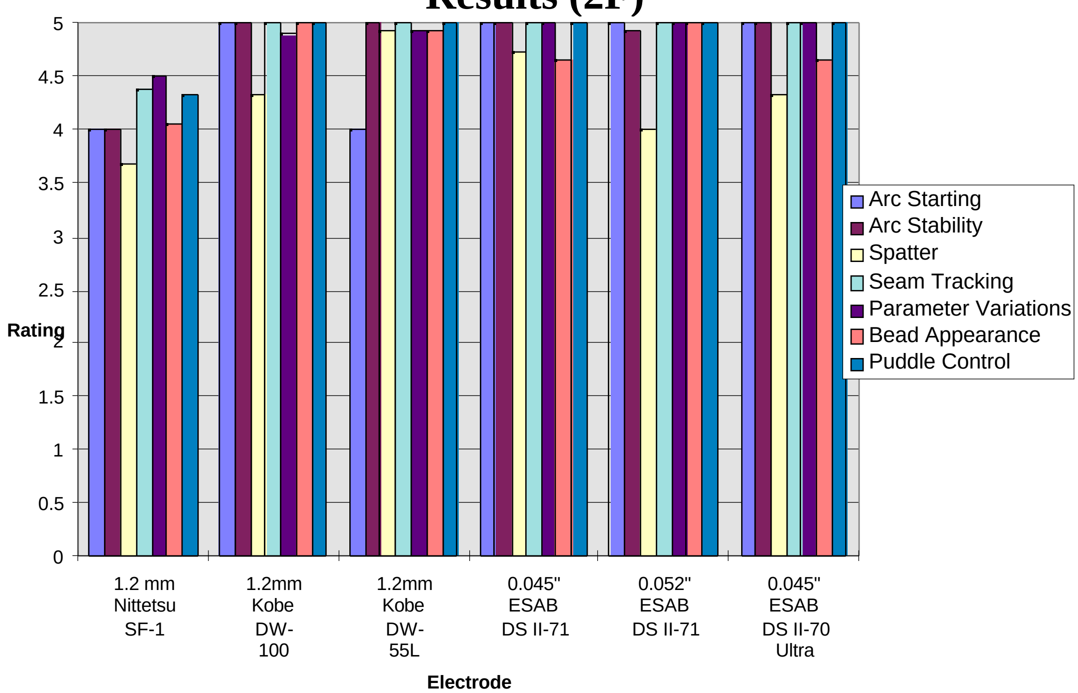
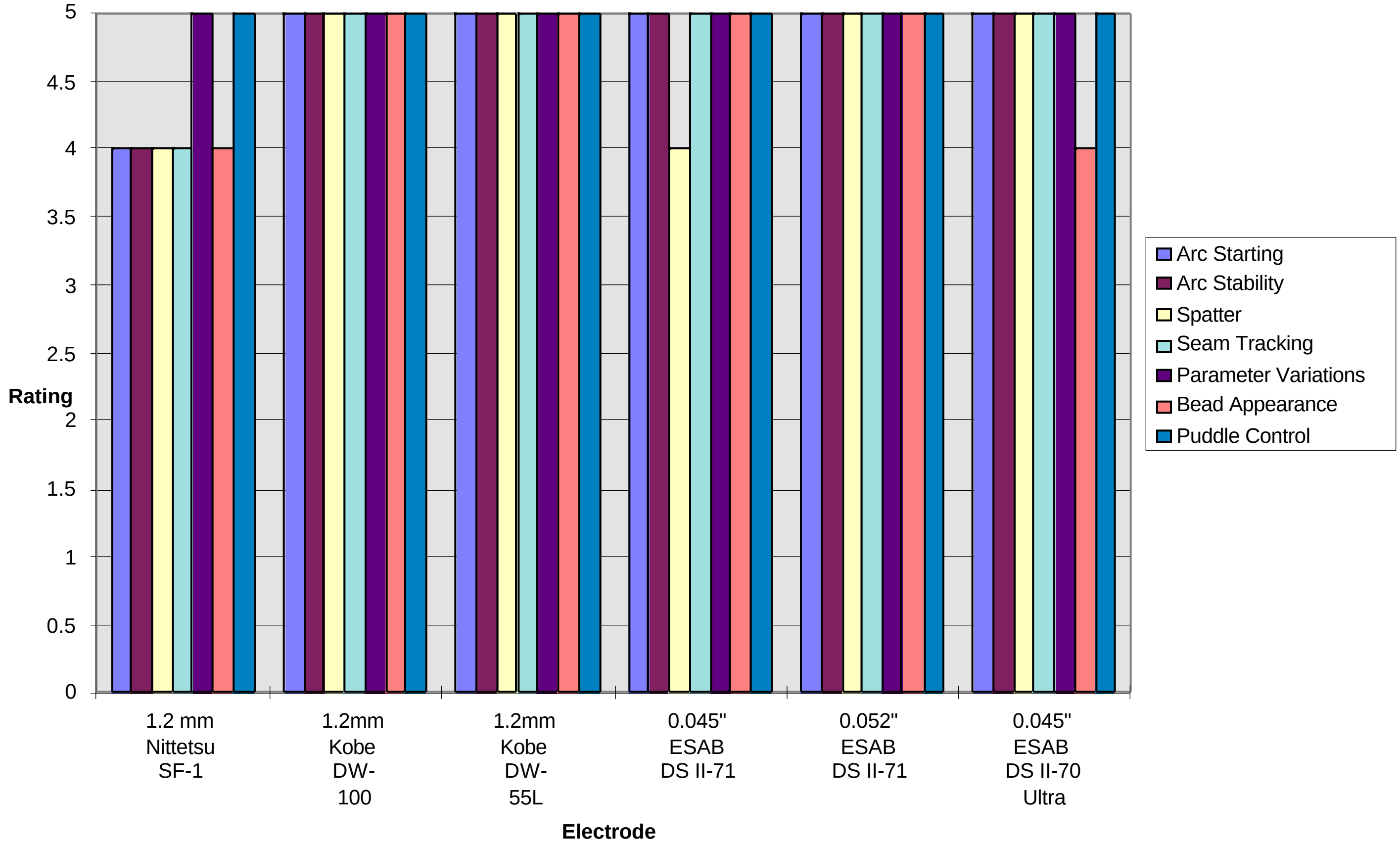


Figure 10

Results (3F)

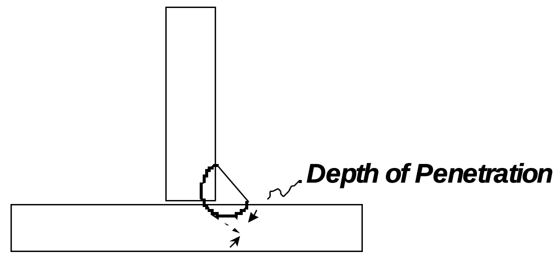


B. *Root Penetration*

Method:

Of the joints welded in subsection A above, one joint was taken from each position for each wire and macro-etched to determine the amount of penetration into the base metal at the root. Figure 11 shows method of measuring root penetration.

Figure 11
Method - Measuring Penetration

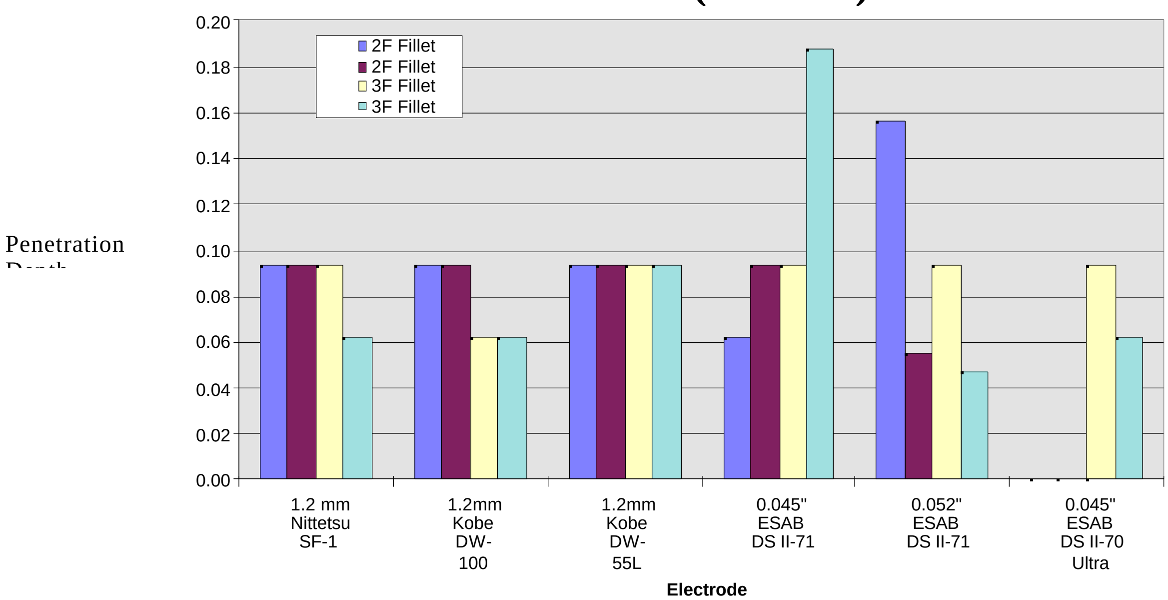


Results:

The weld macros showed all wires welded with acceptable root penetration. Figure 12 shows the penetration obtained with the different wires. The electrodes using 100% CO_2 exhibited more penetration in the 2F position than the wire using 75% AR - 25% CO_2. In the 3F position, the penetration was similar for all electrodes.

Wires using 100% CO_2 shielding gas generally exhibit more penetration than wires using 75% AR - 25% CO_2. Carbon dioxide's higher thermal conductivity (due to the dissociation and recombination of its component parts), transfers more heat into the base metal.

Figure 12
Results - Penetration (2F & 3F)

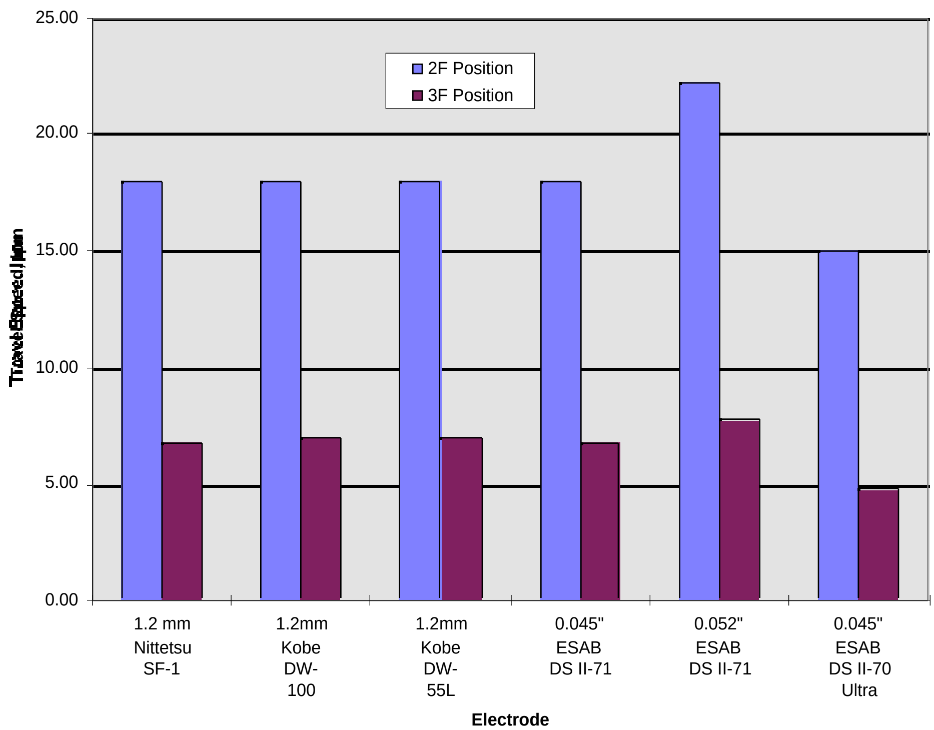


C. ***Welding Travel Speed:***

The travel speeds between wires for a given weld size were compared as shown in Figure 13. The .052" diameter ESAB DS II-71 had the fastest travel speeds (24% faster in the 2F position and 11% faster in the 3F position than the other 100% CO_2 electrodes) while the .045" diameter ESAB DS II-70 Ultra using the 75% Ar - 25% CO_2 shielding gas had the slowest (17% slower in the 2F position and 30% slower in the 3F position than the other similar sized 100% CO_2 electrodes). The faster travel speeds obtained with the 100% CO_2 electrodes is attributed to the higher optimum welding parameters achieved with 100% CO_2 shielding gas.

Figure 13

Travel Speed Comparison



D. ***Conclusions:***

The following can be concluded from the automatic (robotic) evaluation:

- ♦ All wires had comparable operability in the type of welds tested.
- ♦ When parameters were optimized for operability, the 100% CO_2 wires yielded faster travel speeds than the 75% Ar, - 25% CO_2 wire.

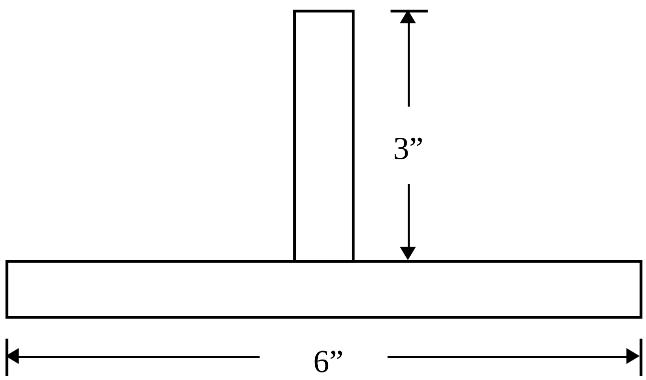
- The 100% CO_2 wires provided more root penetration than the 75% Ar, - 25% CO_2 wire. This increased penetration could allow decreased fillet weld sizes without a loss in overall weld strength.

- There was not a great difference between the domestic and foreign wires using 100% CO_2. The robotic operator did prefer Kobe DW 55L because it had a slightly smoother arc.

Part III: <u>MULTIPASS WELDING OVER SLAG</u>

<u>Method:</u>

Eighteen fillet weld test assemblies were fit-up using 1/2" thick ABS Grade A plate. All test assemblies were 18" long. All joints were sanded to bare metal. The joint design is shown below.



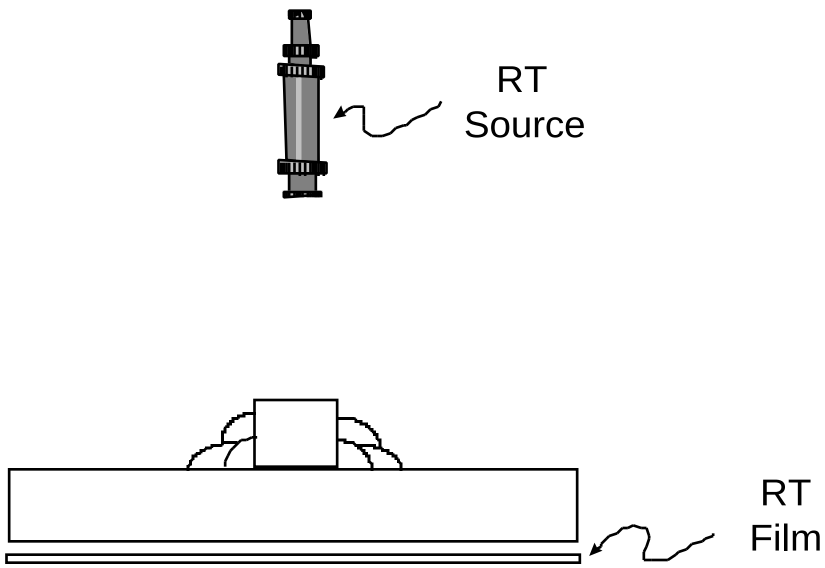
Each wire was used to weld 3 test assemblies. All three test assemblies were welded at the optimum parameters established for each wire. A **3** pass weld was made on each side of the web. The slag was not removed until the final pass was completed.

The welding technician and engineer evaluated each wire for its starting characteristics, arc stability, amount of spatter, seam tracking, parameter variations and bead shape and appearance.

To check for trapped slag, one of the three joints welded with each wire was macro-etched. Additionally, the flanges were cut off 1/8" above the fillet weld toes and the joints were radiographically (RT) inspected as shown in Figure 14.

Figure 14

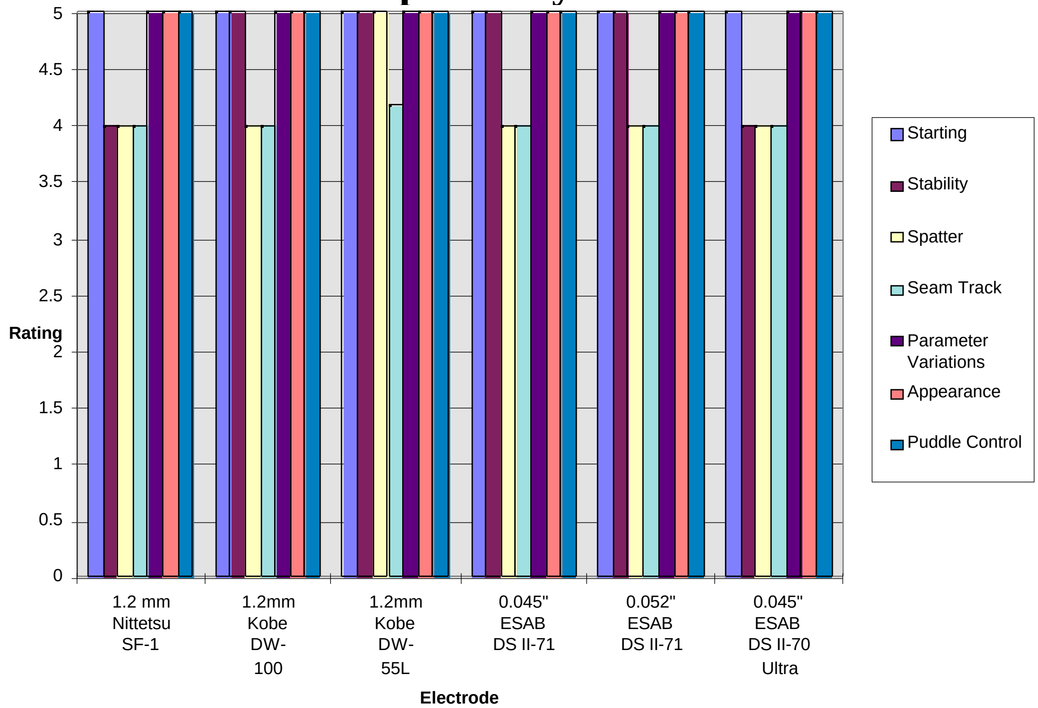
RT Method - Fillet Welds



Results:

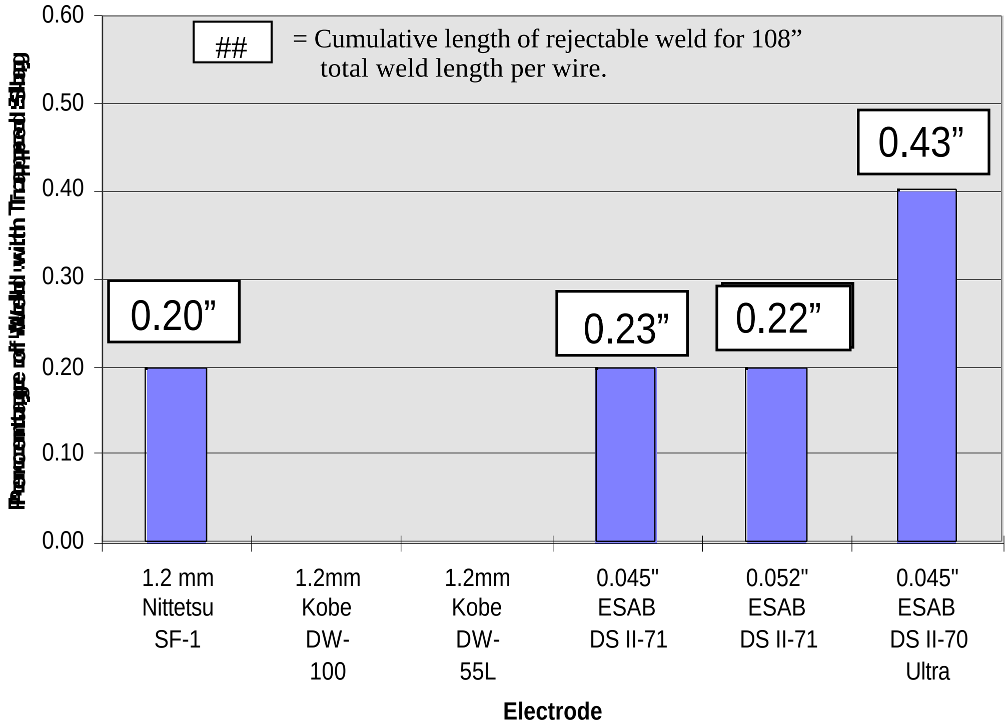
Figure 15 shows each average rating of the operability characteristics. There was not a great difference in operability between wires when welding over slag.

Figure 15
Operability Results



The weld macros showed no visible slag trapped between weld beads. The RT results showed very little trapped slag between weld beads for all wires. The minute amount of trapped slag found in the RT results was in the starts and stops of the weld beads. The wire using 75% Ar - 25% CO_2 had the highest amount of slag (0.43”); However, that amont still is less than 0.5% of the weld length. In a fillet weld break test, MIL-STD 248 allows indications up to 3/32” long in an 18” weldment. This equates to 0.52%. Figure 16 shows the RT results.

Figure 16
RT Results


##
= Cumulative length of rejectable weld for 108” total weld length per wire.
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.20”
0.23”
0.22”
0.43”
1.2 mm Nittetsu SF-1
1.2mm Kobe DW-100
1.2mm Kobe DW-55L
0.045" ESAB DS II-71
0.052" ESAB DS II-71
0.045" ESAB DS II-70 Ultra
Electrode

Conclusion:

The following can be concluded from the multipass welding over slag evaluation:

- All 6 wires were capable of welding fillet welds over slag with acceptable results.
- The presence of slag on previous beads had no adverse affects on the operability of any of the wires.
- Subsequent beads adequately burned out the existing slag and penetrated into the previous beads, producing sound welds.

Part IV: PROJECT CONCLUSIONS

Within the scope of conditions evaluated in this project, there was no significant difference between the foreign and domestic wires. It should be noted that this evaluation did not include testing every possible condition, including:

- Consistency of optimum parameters from heat to heat.
- Ability to weld through primer and toleration for other contaminants.
- Diffusible hydrogen levels and resistance to absorbing hydrogen.

Based on testing performed in this program, there was some differences noted that are attributed to the different shielding gases. Specific observations and advantages/disadvantages are summarized below:

Semiautomatic and Mechanized Evaluation:

- All wires were capable of producing sound welds as demonstrated by VT, MT, macros, fillet break tests, and RT of butt welds.
- The operability of ESAB's DS II-70 Ultra wire which used 75% Ar - 25% CO_2 was preferred over the wires using 100% CO_2. This preference was especially prevalent for out of position welding.

- ♦ The slag removability during fillet welding was comparable for all wires. There was no great differences noted between wires.

- ♦ For butt welding, the ESAB wires' slag was easily removed while the Kobe and Nittetsu wires produced tightly adhering slag.

- ♦ There were small overall differences in the amount of smoke/fumes generated between wires. ESAB's DS II-70 Ultra had the least amount of smoke/fumes which was attributed to the 75% Ar - 25% CO_2 shielding gas.

Automatic (*Robotics)* Evaluation:

- ♦ All wires had comparable operability in the type of welds tested.

- ♦ When parameters were optimized for operability, the 100% CO_2 wires yielded faster travel speeds than the 75% Ar, - 25% CO_2 wire.

- ♦ The 100% CO_2 wires provided more root penetration than the 75% Ar, - 25% CO_2 wire. This increased penetration could allow decreased fillet weld sizes without a loss in overall weld strength.

- ♦ There was not a great difference between the domestic and foreign wires using 100% CO_2. The robotic operator did prefer Kobe DW 55L because it had a slightly smoother arc.

Multipass Welding Over Slag

- ♦ All 6 wires were capable of welding fillet welds over slag with acceptable results.

- ♦ The presence of slag on previous beads had no adverse affects on the operability of any of the wires.

- ♦ Subsequent beads adequately melted the existing slag and penetrated into the previous beads, producing sound welds.

Part V: <u>PROJECT RECOMMENDATIONS</u>

As demonstrated by the aforementioned conclusions, the major differences noted during this evaluation were not between wire manufacturers (foreign or domestic). In the

tests performed under this program, the domestic wires, utilizing 100% CO_2 shielding gas, were equitable with their foreign counterparts. **Based on these results, it is recommended that subsequent phases of this project, which were to focus on reformulation and development of an improved domestic wire, be suspended.**

This evaluation did, however, bring to light some distinct differences associated with the shielding gases used (100% CO_2 vs. 75% Ar, - 25% CO_2). The following recommendations are provided to fully take advantage of these differences:

- The 100% CO_2 wires could be utilized in robotic operation to obtain higher travel speeds. The minimal amount of spatter associated with the 100% CO_2 wires (comparable with the 75% Ar - 25% CO_2 wire) further enhance the potential for automation.

- Productivity increases, associated with faster travel speeds, could possibly be achieved with 100% CO_2 wires in mechanized and certain semi-automatic applications.

- Fillet size reduction from greater penetration of 100% CO_2 wires could result in significant savings due to less weld time, reduction of consumables used and less distortion.

- Due to its better operability in semiautomatic out of position testing, the 75% Ar, - 25% CO_2 wire should be considered for out of position welding.

- There is an indication that the 75% Ar - 25% CO_2 wire is advantageous in reducing the amount of fumes.

- Serious consideration should be directed toward minimizing interpass cleaning in fillet welds deposited with the FCAW process. All of the wires evaluated in this project demonstrated the ability to weld over slag in fillet welds with acceptable results.

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